Response of Lake Trout and Rainbow Trout to Dietary Cellulose

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Contents

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Abstract

In a 16-week study, duplicate groups of lake trout, *Salvelinus namaycush* (mean weight, 0.82 g), were fed a natural-ingredient diet that was geometrically diluted with 2 to 32% wood cellulose. To ensure that all fish were offered the same quantity of nutrients, I increased the daily ration of each diet in proportion to the percent dilution of the basal diet. Criteria used to measure the effects of added cellulose were growth, feed conversion efficiency (feed:gain and nutrient:gain ratios), body composition, digestible nutrients (nitrogen and energy), and metabolizable energy. Increments of supplemental cellulose linearly suppressed growth and the feed:gain ratio. The effect of cellulose on growth was described by the function, $\hat{Y} = 9.45 - 0.09X$ ($r = -0.97$), where $\hat{Y}$ = 16-week gain in grams, X is supplemental cellulose as percent of diet, and $0 \leq X \leq 32$. The influence of cellulose on the feed:gain ratio was described by the function, $\hat{Y} = 1.51 + 0.01X$ ($r = 0.92$), where $\hat{Y}$ = feed:gain ratio, X is supplemental cellulose in percent of diet and $0 \leq X \leq 32$. Expression of food conversion on a nutrient:gain basis removed most of the linear slope that reflected the influence of level of dietary cellulose. When rainbow trout, *Salmo gairdneri* (mean weight $\geq$ 200 g), were force-fed increased amounts of diet to compensate for dilution of nutrients, metabolizable energy of diets increased at the lower percentages of cellulose (0–4%), but then decreased at about 8%. The diluting effect of the smaller percentages of cellulose apparently increased the availability of the basal ingredients. Fish were unable to consume enough feed of low-energy density (containing 16 to 32% cellulose) to maintain normal growth. Dilution and decreased bioavailability of nutrients were thus implicated as the causes of adverse effects induced by supplemental dietary cellulose.

The use of plant products in natural-ingredient fish feeds has included the introduction of various amounts of cellulose and other complex carbohydrates. Although wide ranges in amount of cellulose and hemicellulose have been used as diluents and binders in experimental fish diets (Cowey et al. 1971; Lee and Putnam 1973; Poston 1975; Bromley and Adkins 1984), the possibility of providing cellulose and other components of fiber to increase the use of nutrients by increasing dietary bulk has not been extensively studied. Excessive amounts of diluent may prevent fish from eating enough food to support normal fish growth. Leary and Lovell (1975) found that, among channel catfish (*Ictalurus punctatus*) held in ponds, fish fed diets containing 2 or 8% wood cellulose grew faster than those fed 14 or 20% wood cellulose. However, Buhler and Halver (1961) reported that, although growth and food consumption in salmonids were inversely proportional to the molecular weight of carbohydrates consumed, small amounts of supplemental cellulose increased growth and efficiency of protein use by chinook salmon (*Oncorhynchus tshawytscha*). Smith (1971) also reported that a small amount (13.7%) of digestion and absorption of cellulose occurs in salmonids.

The present study was designed to investigate the effect of feeding a pelleted production diet containing up to 32% of geometrically graded levels of wood cellulose on the growth and feed utilization of fingerling lake trout (*Salvelinus namaycush*) and on digestible and metabolic energy of rainbow trout (*Salmo gairdneri*).

Materials and Methods

Duplicate groups of 50 fingerling lake trout each (initial body weight, 0.82 ± 0.03 g) were fed geometric gradations (0, 2, 4, 8, 16, and 32%) of supplemental wood cellulose (Solka-floc) for 16 weeks. The cellulose gravimetrically replaced equivalent amounts of a ground production salmonid starter diet (Tables 1 and 2). After incorporation of the cellulose, the diets were repelleted without steam in a laboratory pellet mill, crumbled, and screened into edible sizes according to Federal specifications (National Research Council 1981).

Experimental fish were held in 6.5-L jars at 10°C. All fish were weighed at 2-week intervals during the experiment. Fish were fed the different diets as a percentage of body weight. To offer all fish the same amount of nutrients, I increased the daily feed allowance in proportion to the percent dilution of the basal diet by cellulose, which was assumed to be nutritionally unavailable. Accordingly, fish fed 0, 2, 4, 8, 16, and 32% cellulose initially were offered 5.0, 5.1, 5.2, 5.43, 5.95, and 7.35% of their body weight as food, distributed among eight feedings per day. Daily feeding levels were gradually reduced during the study; for fish fed the basal diet the reduction was to 4.0, 3.0, and 2.5% of body weight when average weights were 2.5, 4.6, and 8.0, respectively.

At the end of 16 weeks, fish were analyzed for proximate carcass composition. Fillet muscle from fish fed each diet was analyzed by gas liquid chromatography for fatty acid composition of lipids. The lipid-extracted fraction of the muscles was saponified and methylated by the modified boron trifluoride methanol technique

Table 1. *Composition of basal diet.*[a]

Ingredient	Percent of diet
Herring fish meal	40.0
Corn gluten meal	10.0
Soybean meal	10.0
Wheat middlings	8.5
Meat and bone meal	5.0
Sardex[b]	5.0
Brewer's dried yeast	5.0
Dried whey	5.0
Soybean oil	10.0
Mineral mix[c]	0.5
Vitamin mix[c]	1.0

[a]Basal diet contained 1.6% cellulose.
[b]Dried condensed fish solubles, Amburgo, Inc., Philadelphia, Pa.
[c]Rumsey and Ketola (1980).

Table 2. *Composition of experimental diets.*

Supplemental cellulose (% of diet)	Ash (%)	Fat (%)	Protein (%)	Moisture (%)	Gross energy (kcal/kg)
0	12.4	15.2	47.4	7.4	4,987
2	12.4	14.9	46.2	7.8	4,957
4	11.9	14.6	45.0	7.5	4,956
8	11.4	14.3	42.6	8.2	4,936
16	10.6	13.3	38.8	9.3	4,915
32	8.7	10.3	31.4	9.1	4,784

of Metcalfe and Schmitz (1961). Fatty acid methyl esters were analyzed on a Hewlett Packard 5880A gas chromatograph with a flame ionization detector and a coiled steel column packed with Silar 10C on 100/120 mesh GasChrom Q11.

To investigate the influence of dietary cellulose on the digestible and metabolizable energy (ME) content of the diets, I force-fed each of the experimental diets (0, 2, 4, 8, 16, and 32% cellulose), by intubation, to five or more rainbow trout weighing at least 200 g each. (Rainbow trout were used in this calorimetry study because lake trout were not available.) The test fish were restrained individually in metabolism chambers designed by Smith (1971) and fed at 1% of body weight per day for 4 days. Use of the metabolism chamber enabled separate quantitative collections of branchial, fecal, and urinary excretions.

Another group of similar rainbow trout were force-fed the diets containing 0, 16, and 32% supplemental cellulose. In the second calorimetry assay, in compensation for dilution of nutrients by cellulose, fish fed 16 and 32% cellulose were fed 1.2 and 1.47 times, respectively, the amount fed those given the basal diet. Most intubated fish retained all food without regurgitation. Energy data were used only from fish that did not regurgitate. Calorimetry of the whole diets and excretions was conducted with an adiabatic oxygen bomb calorimeter according to the method of Smith (1971).

Results

Although the amount of feed offered to lake trout was increased to compensate for the progressive reduction of nutrient density by cellulose in the different diets (Table 2), fish growth decreased linearly as amounts of cellulose increased (Fig. 1). The effect of cellulose on the 16-week growth of lake trout was described by the predictive linear function $\hat{Y} = 9.45 - 0.09X$ ($r = -0.97$), where $\hat{Y}$ = 16-week

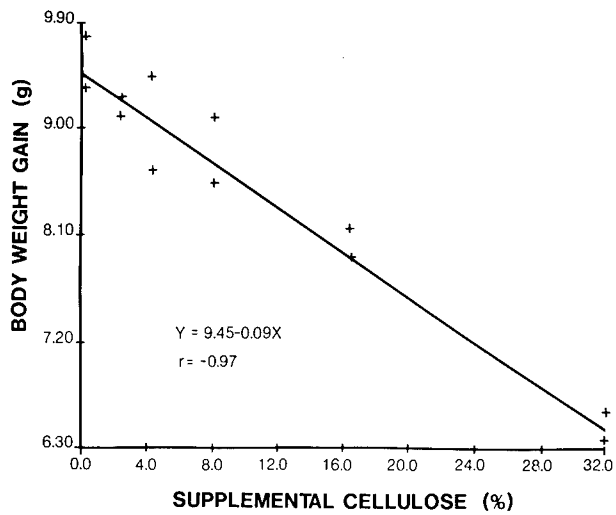

Fig. 1. Relation between body weight gain of lake trout and supplemental dietary cellulose.

weight gain in grams, X is supplemental cellulose content (percent of diet), and $0 \leq X \leq 32$. Analysis of variance and Duncan's New Multiple Range Test (Steel and Torrie 1960) showed that the weight gain of trout fed 8% or more supplemental cellulose was significantly lower ($P \leq 0.05$) than that of fish fed the basal diet. The gain was significantly less in fish fed 16 or 32% added cellulose than in those fed 8% or less.

Feed:gain ratios increased as the level of supplemental cellulose increased; thus the efficiency of feed conversion was likewise linearly suppressed (Fig. 2). The effect of cellulose on 16-week feed:gain ratios is described by the predictive linear function $\hat{Y} = 1.51+0.01X$ ($r = 0.92$), where $\hat{Y}$ = feed:gain ratio, X is supplemental cellulose (percent of diet), and $0 \leq X \leq 32$. The feed:gain ratios for lake trout fed 4, 8, 16, or 32% supplemental cellulose were significantly higher than those for fish fed 2% cellulose or the basal diet. Feed:gain ratios were significantly higher in fish fed 32% supplemental cellulose than in those fed any other diet.

The linear relation between supplemental cellulose and nutrient:gain ratio (obtained by multiplying feed:gain ratios by the percentage of basal nutrient mixture retained in each diet) did not change significantly (Fig. 3). However, a drop in nutrient efficiency, in relation to level of cellulose, was apparent in diets containing 16 and 32% cellulose.

Proximate analysis of the carcasses showed that cellulose content significantly affected carcass composition (Table 3). Whole carcasses of fish fed 32% supplemental cellulose contained significantly less ($P \leq 0.05$) fat and dry matter than did those of fish fed lower concentrations of cellulose, and more protein than those fed no cellulose. Protein content was also higher in trout fed 2 to 16% cellulose than in those fed no cellulose.

The lipid content of muscle fillet of the experimental fish progressively decreased with each increase in dietary cellulose. However, the concentration of the n-3 fatty acid, docosahexaenoic acid, generally

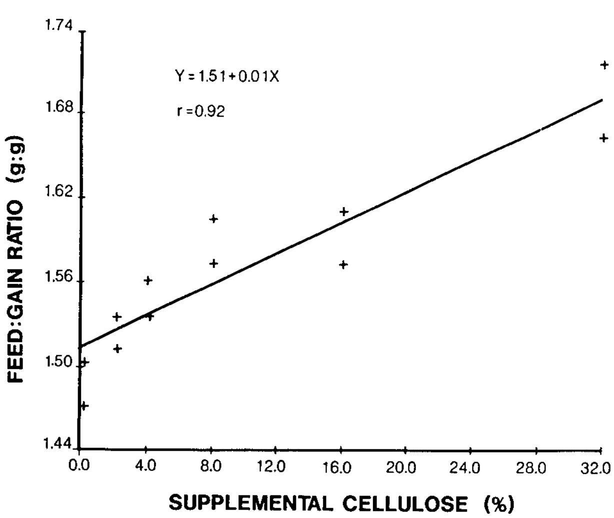

Fig 2. Relation between feed:gain ratio of lake trout and supplemental dietary cellulose.

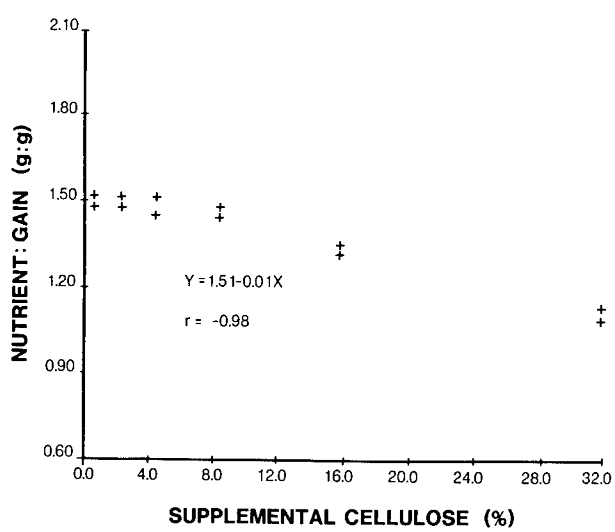

Fig. 3. Relation between nutrient:gain ratio of lake trout and supplemental dietary cellulose. Nutrient:gain ratio = feed: gain × percent concentration of dietary nutrients.

Table 3. *Effect of level of supplemental dietary cellulose on composition of lake trout.*[a]

Supplemental cellulose (% of diet)	Composition as percent of dry matter: Ash	Fat	Protein	Dry matter (%)	Docosahexaenoic acid (% fillet fat)[b]
0	8.4^{x}	27.9^{x}	60.7^{x}	24.3^{x}	6.4
2	8.6^{x}	28.2^{x}	62.5^{y}	24.3^{x}	7.3
4	8.6^{x}	27.0^{x}	$63.1^{y,z}$	23.9^{x}	6.8
8	8.6^{x}	27.5^{x}	$63.0^{y,z}$	24.2^{x}	7.7
16	8.4^{x}	26.0^{x}	$64.1^{y,z}$	23.9^{x}	7.5
32	9.2^{x}	23.7^{y}	64.3^{z}	23.0^{y}	8.3

[a]Values in same column sharing common superscript are not statistically different ($P \leq 0.05$).
[b]Single fatty acid analyses precluded statistical evaluation.

increased in the muscle lipid of all fish fed supplemental cellulose (Table 3).

In the calorimetry studies with rainbow trout, the apparent digestible energy and ME of fish force-fed at 1% of their body weight increased in fish fed 2 and 4% cellulose, and then decreased with further increments of cellulose (Table 4). The greatest decrease was in fish fed 32% supplemental cellulose. After the ME values were adjusted for concentration of nutrients (Table 4), the corrected ME values increased numerically with each increment in dietary cellulose. In the second calorimetry assay, in which equivalent levels of nutrients of diets containing 0, 16, and 32% cellulose were force-fed to compensate for dilution of nutrients by cellulose, the cellulose at both levels suppressed dietary ME (Table 5). On a per-nutrient basis, however, corrected ME increased with the addition of 32% cellulose, compared with a decrease in ME when there was no compensation for dilution of nutrients (Table 5).

Discussion

Although the addition of small amounts of cellulose increased ME values of the whole diet, this increase was probably exerted on the basal diet ingredients, rather than on cellulose itself. Sibbald et al. (1960) attributed a similar increase in ME values in the chicken to the diluting effect of cellulose, which resulted in increased use of the basal portion of the diet. The increase in ME in some fish diets could not be used because of the large additions (16 and 32%) of cellulose.

Differences in body composition, growth, and feed:gain and nutrient:gain ratios were gradual and small in fish fed the smaller amounts of cellulose. The rate of growth reduction accelerated when dietary cellulose exceeded 8%. Results of this and other studies indicate that the level of 2,900 kcal/kg of diet is the concentration of energy below which salmonids apparently can no longer physically compensate for reduced dietary ME by increasing the intake of feed. In the present study, this limit was reached near 16% cellulose (Table 5). Fish fed diets containing 16 and 32% cellulose were physically unable to eat enough to meet energy requirements for normal growth; corrected ME values (Table 5) indicated, however, that they made more efficient use of the limited nutrients available at the two highest levels of cellulose.

In a feeding experiment parallel in design to the present one, Bromley and Adkins (1984) diluted a high-quality fish meal diet with levels of cellulose as high as 50% of the diet. Rainbow trout fed these diets

Table 4. *Apparent effect of cellulose concentration on utilization of nutrients by lake trout and rainbow trout.*[a]

Concentration of nutrients in diet[b] (%)	Apparent digestible nitrogen (%)	Digestible energy (%)	Metabolizable energy (kcal/kg)	Corrected metabolizable energy[c] (kcal/kg)	16-Week weight gain (g)	Feed:gain (g:g)	Nutrient:gain (g:g)
100	74.08	70.9	3,104	3,104	10.4	1.50	1.50
98	74.87	77.6	3,325	3,392	10.0	1.52	1.50
96	77.26	81.2	3,740	3,899	9.8	1.55	1.49
92	74.37	79.2	3,347	3,692	9.7	1.58	1.47
84	74.89	73.7	2,916	3,471	9.0	1.58	1.30
68	77.77	65.9	2,812	4,135	7.4	1.68	1.15

[a]Calorimetry data were collected from rainbow trout; other data were obtained with lake trout.
[b]Nutrient concentration = 100 minus percent cellulose in diet.
[c]Metabolizable energy (ME) adjusted for dilution of nutrients in diet (corrected ME = ME ÷ nutrient concentration).

Table 5. *Effect on metabolizable energy (ME) of force-feeding increased amounts of diet to rainbow trout to compensate for dilution of nutrients.*[a]

Concentration of basal nutrients (% of diet)	ME (kcal/kg diet)	Corrected ME (kcal/kg nutrients)
100	3.10	3.35
84	2.92	3.47
68	2.63	3.87

[a]Trout were force-fed diets with 84 and 68% nutrient concentration at 1.2 and 1.47 times, respectively, the amount fed those receiving the undiluted diet.
[b]ME adjusted for dilution of nutrients in diet (corrected ME = ME ÷ nutrient concentration).

compensated for up to 30%—but not 40%—cellulose by increasing the total weight of food eaten and thus stabilizing both nutrient intake and growth rate. If one uses the authors' gross energy value of 4,900 kcal per kilogram of nutrient mixture, and a realistic value of 85 kcal ME per 100 kcal of gross energy, the ME value of a diet containing 70% nutrient mixture (i.e., 30% cellulose) is 2,915 kcal/kg diet. As in the present study, growth rate declined rapidly at values below the 2,900 kcal ME calculated for the 70% nutrient mixture. Smith (1980) found that the addition of up to 10% of a nonnutritive clay (sodium bentonite) to the diet of rainbow trout also improved the conversion efficiency of the nutritive portion and usually improved fish growth; the addition of more than 10% clay reduced growth rate and feed utilization efficiency.

It is not clear if these adverse effects on growth are totally due to lower intake of nutrients or also to a direct adverse effect of the inert ingredients on digestion or absorption (Bromley and Adkins 1980). However, the response of ME values and nutrient:gain ratio to force-feeding of compensatory levels of nutrients in the calorimetry tests supported the suggestion that the effects of increased cellulose were caused by the dilution of available nutrients—especially digestible energy. The elevation of muscle docosahexaenoic acid is also a sign of restricted intake of nutrients (Takeuchi and Watanabe 1982).

Increased production of carcass protein by cellulose or other diluents could be desirable in the trout industry if a premium is paid for fillets containing protein. However, this would be economically feasible only when the increased demand is not offset by reduced fish growth.

The use of feeds containing cellulose or other inert ingredients has certain drawbacks. Other workers have shown that low-energy foods are evacuated from the intestinal tract of fishes more rapidly than are those of higher energy density (Grove et al. 1978; Jobling 1981; Flowerdew and Grove 1979; Elliot 1972; Hilton et al. 1983; Bromley and Adkins 1984). Feeding diets with intermediate energy density high enough to support economic fish growth would therefore result in the release of increased quantities of excreta. A large increase in indigestible wastes would increase pollution of the water, necessitating aeration of hatchery water supplies, and perhaps the cleanup of discharge effluents. Additionally, increased bulk from added nonnutritive filler increases transportation and marketing costs.

Many of the fish fed in the calorimetry study were in negative nitrogen balance; however, no specific constant has been developed to correct for nitrogen gained or lost during the assay. Constants developed for uric-acid-excreting birds or urea-excreting mammals cannot safely be used for ammonia-excreting fish. Furthermore, the merits of nitrogen correction factors are still being debated (Sibbald 1982).

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Key words: Lake trout, cellulose, dietary diluent, growth, feed conversion, nutrient conversion, metabolizable energy, digestible energy, feed intake.

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